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Hansen, Thor; Møller, Eva B.

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## Field measurements of moisture variation in cold ventilated attics with different ceiling constructions

Thor Hansen<sup>a\*</sup>, Eva B. Møller<sup>a</sup>

<sup>a</sup>Aalborg University Copenhagen - SBI, A. C. Meyers Vænge 15, Copenhagen SV 2450, Denmark

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### Abstract

Adding insulation material on ceilings against cold ventilated attics is one of the most straightforward tasks of adding insulation. Theoretically, a higher amount of insulation in the attic decreases the temperature and consequently the capability of removing infiltrated indoor humid air. Field measurements of the moisture balance in 20 cold ventilated attics with different amounts of insulation material were analysed. Results show that the amount of insulation material has no decisive effect on temperature in the attic during winter. The moisture level during winter was generally just below the threshold for mould growth.

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**Keywords:** Field measurements; cold ventilated attics; moisture; vapour barrier; insulation thickness

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### 1. Introduction

Where the demand for energy saving in the existing building stock is concerned, adding insulation material on ceilings against cold ventilated attics is one of the most straightforward tasks of adding insulation. Due to a higher amount of insulation on the ceiling, the attic temperature changes and therefore the capability of removing infiltrated humid indoor air in the attic decreases. If the balance between the infiltrated and removed moisture is uneven, moisture accumulations may occur and this may lead to moisture-related damages.

An effective way of reducing moisture transport through the ceiling is to install a tight air-and-vapour barrier. For this reason the general recommendation in Denmark is to install a tight air-and-vapour barrier, if the total insulation material is thicker than 150 mm. The recommendation does not distinguish between different types of insulation material. Establishing a new tight vapour barrier in an old existing building can be rather difficult and therefore

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\* Corresponding author. Tel.: +45 99402209

E-mail address: [thh@sbi.aau.dk](mailto:thh@sbi.aau.dk)

expensive, which in many cases will make the additional insulation non-profitable. In practice, the vapour barrier is omitted in many cases, either due to the cost or no belief in its necessity, the latter being the case especially when the insulation material is cellulose based.

The recommendation has been questioned and therefore a research project is currently being performed. Different factors are studied such as insulation material properties, amount of insulation material, quality of vapour-and-air barrier, indoor humidity level and ventilation rate of the attic. As a part of this study, 30 Danish single-family houses were investigated. All test buildings had ventilated attics, but differed on other factors. In these buildings, temperature and relative humidity were measured for one year in the living space, outdoors and in the attic.

It is expected that the results presented in this paper will contribute to refining the current general recommendation concerning the total amount and type of insulation material on ceilings without a tight vapour barrier against a cold ventilated attic.

## 2. Theory

The water vapour content of the attic air is dependent on the moisture level in the outdoor air and the indoor air entering the attic, either by diffusion through the material or by penetration through leaks in the ceiling (convection).

The driving force for diffusion is the differences in the varying water vapour pressure/humidity of air by volume transporting moisture from high to low level. On the other hand moisture transport due to convection occurs along with air movements which take place when there is an air pressure difference. It is well known that convection has a considerably greater effect on moisture transport compared with diffusion.

## 3. Materials and method

To evaluate the influence of vapour barrier and insulation thickness on the humidity of the air in cold ventilated attics, a field survey was carried out. The following parameters were considered for selecting different dwellings in Denmark:

- The type of vapour barrier, both PE- and Alu-foils were commonly used 30-50 years ago
- The amount of insulation, 100-200 mm insulation material was commonly used 30-50 years ago, while modern ceilings have 400-600 mm
- The type of insulation, mineral wool is the most common insulation material; however the use of cellulose-based materials has increased over the past 10 years

A low ventilation rate of the attic space was expected to have a strong effect on the moisture level, possibly much more effect than the other parameters. In spite of its strong effect, it was not further considered, because it is normally straightforward to establish sufficient ventilation openings.

A total of 30 test buildings were included in this research, but unfortunately 10 test buildings were not included because data collecting was still ongoing. The 30 test buildings are listed in Table 1, where different information is given. All test buildings were categorised in four types,

- Type A, buildings with no vapour barrier
- Type B, buildings with a PE-foil vapour barrier
- Type C, buildings with a Alu-foil vapour barrier and additional insulation based on cellulose
- Type D, buildings with a Alu-foil vapour barrier and additional insulation based on mineral wool

At the same time as installing sensors (EL-USB-2+ from Lascar Electronics [1]) for registration of temperature and relative humidity, the attics were visually inspected for ventilation openings and mould growth. A sensor was installed at the locations shown in Figure 1. Before installation all sensors were controlled for measured variation at high (90%) and low (50%) relative humidity. Each sensor was programmed to register the temperature and relative humidity every hour, which leads to a high fluctuation when data is plotted. Therefore, the raw data were evaluated by calculation of the moving average for a period of one week. For evaluation of the registered temperature and relative humidity,

calculation of the air humidity by volume was performed by using DS/EN ISO 13788 [2]. On the basis of the calculated air humidity by volume, no significant differences were found in the measurements at the sensor position, at the ridge and roof underlay.

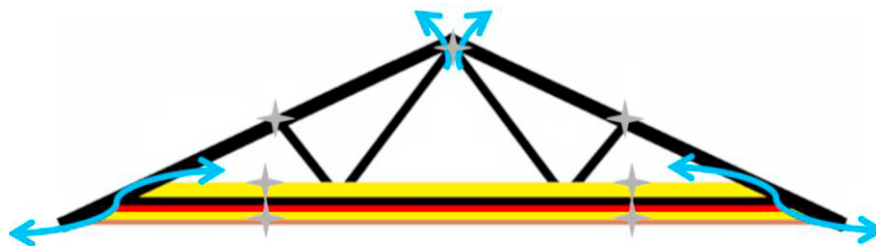


Figure 1 – Principle of cold ventilated attic and sensor location for measuring the relative humidity and temperature in test buildings. Blue arrows indicate ventilation; red line indicates position of possible vapour barrier.

Mould risk is normally set at 75-80% RH at 20 °C [3]. This paper identified winter as the critical period where the temperature is below 10 °C. Therefore, the threshold value for mould was set at 95% RH, according to [3].

Table 1. Shows the test buildings, listed with the different parameters. Each test building is categorised in four different types A, B, C and D (\*is not included in the paper, due to ongoing data collection). In the third column the installation date of the sensor is given, next the erecting year of the building, followed by the type of vapour barrier used. Concerning used insulation material, the original insulation material thickness and type\*\* (CL = cellulose based, MW = mineral wool based) and the amount of additional insulation and type are listed. The last column sums insulation material thickness. D\*\*\* Seven test buildings where data collection is ongoing until mid-April 2017.

Test type	Test number	Date of sensor installation	Year of erecting	Vapour barrier type	Original Insulation, mm	Insulation Type**	Additional Insulation, mm	Insulation Type**	Total insulation, mm
A	01	17-Jul-15	2015	None	600	CL	-	-	600
A	02	23-Jul-15	1964	None	150	MW	200	CL	350
A*	03	21-Jul-15	1935	None	50	MW	300	CL	350
A*	04	11-Dec-15	1956	None	80	MW	170	MW	250
B	05	21-Sep-15	2004	PE-foil	250	MW	-	-	250
B	06	23-Sep-15	1979	PE-foil	200	MW	-	-	200
B	07	7-Aug-15	1996	PE-foil	150	MW	-	-	150
B	08	16-Sep-15	1998	PE-foil	250	MW	-	-	250
B*	09	12-Feb-16	1970	PE-foil	200	MW	250	MW	450
C	10	17-Jul-15	1969	Alu-foil	100	MW	200	CL	300
C	11	22-Jul-15	1969	Alu-foil	100	MW	350	CL	450
C	12	23-Sep-15	1971	Alu-foil	100	MW	200	CL	300
C	13 - 22	26/27-Oct-15	1980	Alu-foil	100	MW	400	CL	500
D	23	20-Oct-15	1971	Alu-foil	100	MW	100	MW	200
D***	24 - 30	Feb-16	1964-76	Alu-foil	100 – 200	MW	150 – 300	MW	250 – 400

#### 4. Results

In the following, the collected data are illustrated by showing the average for Types A to D. Due to only minor differences between data at the ridge and below the roof surface, data in this paper are only given from the sensor position at the ridge. Figure 2 (top) shows the measured temperature, relative humidity and the calculated humidity of air by volume for the whole period of measurements, while other graphs are enlargements of the winter period.

The visual inspection of mould growth showed no visual problems, except building (B-09), where there was condensation on the roof underlay and the surface of insulation material was wet. The same test building had almost no ventilation openings either at the eaves or ridge. Test buildings (B-06 and B-08) had small ventilation openings at the eaves and ridge. In the rest of the test buildings, the ventilation openings were visually assessed and found to

comply with the guidelines, e.g. ventilated through air gaps at eaves and valves or openings at the ridge which means area ventilation openings of 1/500 of the floor area [4].

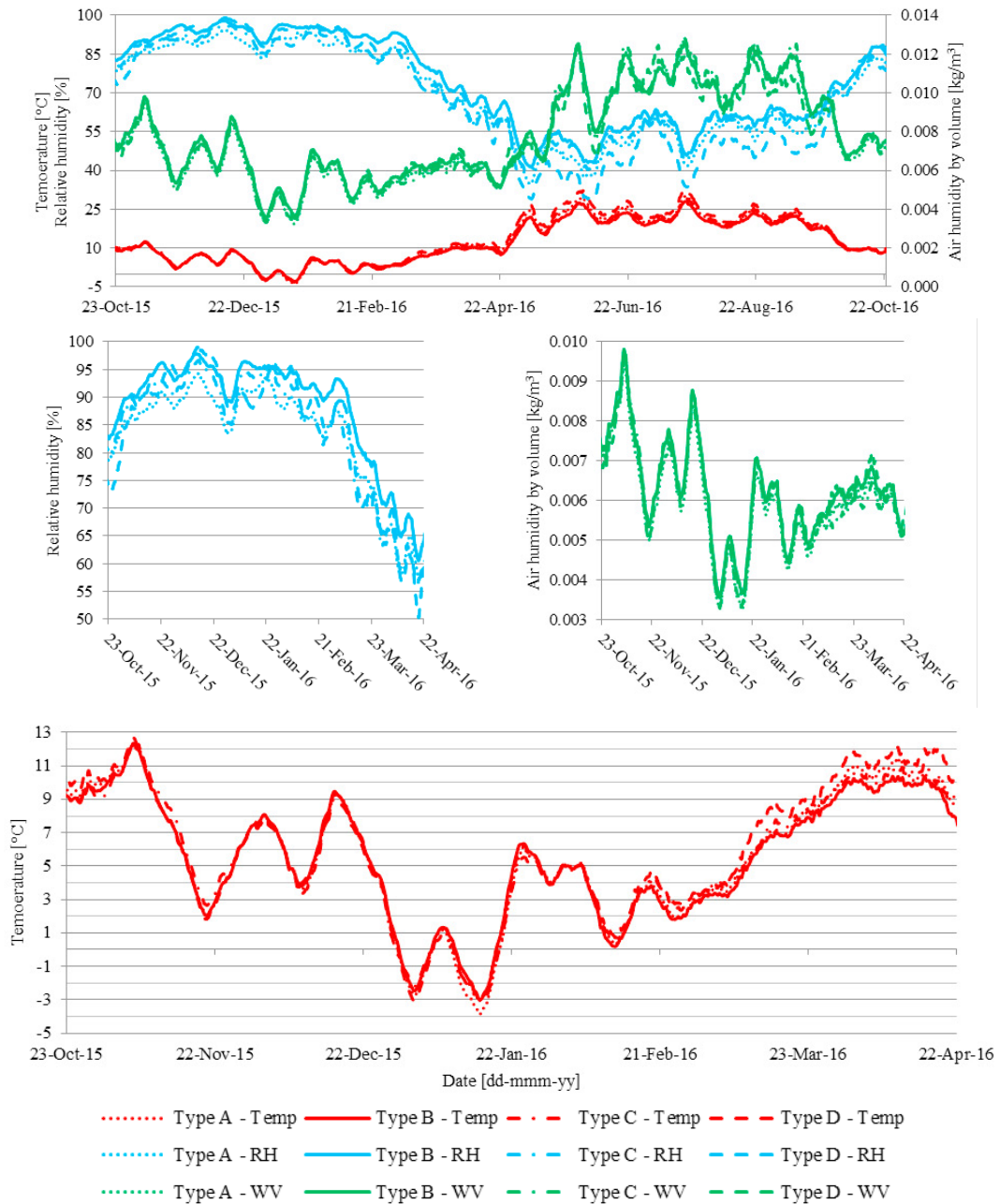


Figure 2 – Hygrothermal conditions in attics of the different test building types described in Table 1. Red lines show the temperature, blue lines the relative humidity, while the green lines (WV) show air humidity by volume.

Figure 3 illustrates the moisture excess to the attic. The figure is based on the calculated humidity of air by volume in the attic subtracted the outdoor humidity of air by volume and in this way it is possible to see when there is a moisture supply to the attic. Table 2 shows mean values and standard deviation in the attic for the winter.

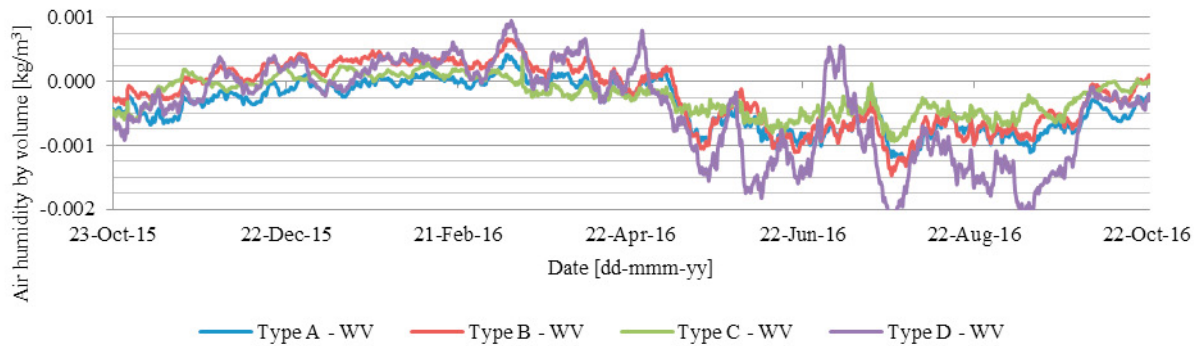


Figure 3 – Moisture excess to the ventilated attic. Difference between the measured outdoor condition and the condition in the attic, positive number higher air humidity by volume in the attic compared with the outdoor climate.

Table 2. Mean values and standard deviation for temperature, relative humidity and moisture excess to the attic in the period 15 November 2015 to 29 February 2016 in the attic and indoor climate.

		Type A	Type B	Type C	Type D
Attic climate	Temperature [°C]	$3.3 \pm 3.1$	$3.4 \pm 3.0$	$3.4 \pm 2.9$	$3.4 \pm 3.0$
	Relative humidity [%]	$89.1 \pm 2.8$	$94.0 \pm 2.2$	$91.2 \pm 3.7$	$92.2 \pm 3.7$
	Moisture excess to the attic [ $\text{g}/\text{m}^3$ ]	$-0.10 \pm 0.14$	$0.24 \pm 0.13$	$0.08 \pm 0.10$	$0.14 \pm 0.23$
Indoor climate	Temperature [°C]	$23.4 \pm 0.3$	$22.6 \pm 0.3$	$21.3 \pm 0.4$	$20.1 \pm 0.9$
	Relative humidity [%]	$39.7 \pm 2.9$	$43.0 \pm 3.3$	$39.4 \pm 4.3$	$48.6 \pm 3.0$

## 5. Discussion

Considering Figure 2 (top graph), the hygrothermal conditions in general seem to be critical only in the winter; the threshold for mould growth of 95% RH at 10 °C was only briefly exceeded during winter, and for this reason the other graphs in Figure 2 are enlarged for the winter period. The discussion concentrates on winter conditions.

The main concern, and reason for this project, was that increased insulation material decreases heat transport through the ceiling and consequently lower the temperature in the attic. Table 2 shows very little difference in the attic temperature in the four types of ceiling, although the average insulation thickness in Types A and C is approx. twice as high as in Types B and D (465 mm and 210 mm, respectively). Simple stationary calculations show that with the same boundary conditions, the difference in winter would be approx. 0.5 °C. There can be different explanations for this discrepancy between theory and practice:

- The indoor temperature may vary. This would mean that the highly insulated houses systematically have higher indoor temperatures than the ones with no extra insulation material. Table 2 shows this is not the case.
- Although all attics except one were ventilated according to the guidelines [4], some of them might have a higher air change rate than others. Higher air change rate decreases the temperature in the attic.
- The roof construction itself may have an influence; roofs with tiles or other heavy cladding means more mass in the attic than roofs with light cladding and this will reduce the temperature fluctuation in the attic.
- There can be regional differences, as some of the houses were located more than 100 km apart.
- The accuracy of the sensors [1] is approx.  $\pm 0.5$  °C, however the temperature was measured by several sensors and the variations were negligible.

The ideal test conditions would have been similar constructions, close to each other and with the same indoor temperature in all houses, the only differences being the amount of insulation material and the quality of vapour barrier. For practical reasons this was not possible, but will later be possible in a full-size test building with different ceilings. Ten houses in the category Type C were in the same neighbourhood and had similar roof constructions

including ventilation. Although the indoor temperature differed, the temperature in the attic was almost the same, the effect and different indoor temperature is therefore not considered to be decisive.

The guideline stating that a vapour barrier is needed when the amount of insulation material exceeds 150 mm is based on experience and explained by the decrease in attic temperature. However, these measurements do not support that the amount of insulation material has a decisive effect on the attic temperature. On the other hand, the number of test buildings is too small to be a substantial reason for changing the guideline.

Figure 2 (mid-left) shows no condensation and fluctuations within 3-6% RH for the different test types. However, Type A in general had a lower moisture level while Type B had a higher level. The moisture excess to attics in Types B and D is positive, while moisture excess to Type C is nearly zero and in Type A negative until mid-December and then nearly zero. From analysing the values in Table 2, there is only a significant difference for the relative humidity between Types A and B. For the moisture excess there is significant difference between Types A and B as well as Types B and C. This might indicate that more insulation reduces the moisture level contrary to the expected outcome. Unfortunately, the different parameters do not vary one at the time, e.g. Type A has no vapour barrier, but a high amount of cellulose-based insulation material, while Type B has a vapour barrier and a small amount of mineral wool. This makes it difficult to distinguish between the impacts of each factor.

Focus on building's airtightness has increased over the past decade; consequently the tightness towards the attic is expected to be improved in the same period. In this research project, newly erected test buildings are not included, as additional insulation material is not expected to be of interest. The exception is test building A-01 from 2015. In A-01, the airtightness is measured to be 0.3 l/s per m<sup>2</sup> building envelop according to the owner. Airtightness was only measured in a few other test buildings, compared with A-01 the airtightness was approx. three times lower.

During the inspection of the test building, the vapour barrier was not inspected more than a couple of places to verify whether there was a vapour barrier and what kind. For performing a total inspection of the vapour barrier it is necessary to remove large amount of insulation material which is difficult and unrealistic in most buildings.

## 6. Conclusion

Measurements in 20 well-ventilated cold attics, categorised in four types of ceiling, constructions do not support the theory that a bigger amount of insulation material decreases the attic temperature during winter and thereby the capability to remove more moisture. Furthermore, neither vapour barrier nor the amount of insulation material nor the different types of insulation material have an essential impact on the moisture level in the attic during the cold period. The moisture level in all four types is below but near the threshold value for mould growth. Therefore, it can be concluded that even small changes may have a negative effect for the attic. Before guidelines should be considered to be changed, more data from existing buildings and a full-size test building are needed.

## Acknowledgements

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